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A Comparison of Soldier Performance in a Moving Command Vehicle Under Manned, Teleoperated, and Semi-Autonomous Robotic Mine Detector System Control Modes

by David R. Scribner and David Dahn

ARL-TR-4609 **September 2008**

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14. ABSTRACT

Soldiers will be required to perform missions using remote technology with increasing frequency as the U.S. Army transforms. Soldiers will be asked to carry out missions that will require them to be at greater standoff distance at the cost of degraded sensory information and resulting limited system performance. Historically, teleoperated systems have had capabilities that are twice the error rate and time required to perform a mission. This is due to the limited field of view, depth perception, vestibular cues, and other immersion reducing characteristics of remote operation. The need to provide operational improvements to the historically degraded teleoperation mode is being recognized by the U.S. Army in many areas, including route clearing and mine detection systems. The Robotic Mine Detection System (RMDS) has provided a system for mine detection and lane marking that allows several modes of operation that are purported to reduce soldier workload and error. These modes include manned operation, teleoperation, teleoperation with cruise control, and semi-autonomous path following. The path following mode is a GPS following mode that allows the Soldier to alter the lateral vehicle course in discrete control inputs known as "biasing" or "bumping." The study was designed to examine these modes of operation comparing the subjective workload, stress, and motion sickness as well as course completion time, average speed, and driving error in terms of lateral drift. Soldiers were asked to operate the RMDS over a secondary course while maintaining proper speed and road edge following under all four conditions. Data for vehicle position and speed were collected at a rate of 5 Hz while subjective ratings of workload, stress, and motion sickness were collected at the mid-and end-points of the course runs. Participants were seven U.S. Army Soldiers and one Department of Defense civilian recruited from Ft. Belvoir, MD. Analysis of variance revealed significant effects for the treatment of control mode on lateral drift distances, course completion times, and stress measures.

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robotics, workload, control modes, soldier performance, teleoperation

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Contents

List of Figures v

List of Tables v

1. Introduction 1

1.1 Advanced Robotic Control Modes 1

1.2 Precision Navigation Modes 2

1.3 Teleoperated Systems Performance Literature 2

1.4 Motion Sickness in Telerobotic Systems 3

1.5 Workload in Telerobotic Systems 4

2. Hypotheses 4

3. Methods 5

3.1 Participants 5

3.2 Apparatus 5

3.2.1 Volunteer Agreement Affidavit 5

3.2.2 Demographic Questionnaire 5

3.2.3 Titmus II Vision Testing Device 5

3.2.4 ARL Robotics Program Office Fort Indiantown Gap Operations Center 5

3.2.5 XUV Teleoperated Vehicle 6

3.2.6 RMDS Control Station 7

3.2.7 Specific Rating of Events (SRE) 7

3.2.8 NASA Task Load Index (NASA TLX) 7

3.2.9 Motion Sickness Assessment Questionnaire (MSAQ) 7

3.3 RMDS Control Modes 8

3.4 RMDS Vehicle Operation Scenario 8

3.5 Design and Analysis 9

3.5.1 Independent Variables 9

3.5.2 Dependant Variables 9

4. Procedure and Methodology **9**

5. Results **11**

6. Discussion **16**

7. Conclusions **18**

8. References **19**

Appendix A. Volunteer Agreement Affidavit **23**

Appendix B. Demographic Data Collection Form **29**

Appendix C. Specific Rating Of Events (SRE) Form **31**

Appendix D. NASA Task Load Index (NASA-TLX) **35**

Appendix E. Motion Sickness Assessment Questionnaire (MSAQ) Form **39**

Distribution List **41**

List of Figures

Figure 1. Husky mine detection and RG-31 control station vehicles. 2
Figure 2. Aerial view of ARL robotics test course (yellow dashed line) at Fort Indiantown Gap, PA. 6
Figure 3. XUV followed by moving command HMMWV..6
Figure 4. RMDS surrogate operator control station...7
Figure 5. Lateral drift (m) by control mode (p = 0.000). 13
Figure 6. Course time (s) by control mode (p = 0.000). 14
Figure 7. Overall workload ratings by control mode (p = 0.058.) 14
Figure 8. Overall workload change scores by control mode (p = 0.062). 15
Figure 9. Stress ratings by control mode (p = 0.029). 15

List of Tables

Table 1. Study condition presentation. 10
Table 2. ANOVA table of dependant measures..12
Table 3. Estimated maximum operation time by mode type (n = 8). 12
Table 4. Rank order of preferred remote operation modes (n = 8). 12

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1. Introduction

Teleoperated systems development has been increasing for U.S. Army applications. Teleoperated land systems for route-clearing, mine-clearing, and convoy operations have had significant increases in attention by the U.S. Army. Teleoperation is the remote control of a system, usually via radio link, that includes visual and or other feedback to “immerse” the operator into the remote environment. The task of driving is known to induce high workload in military systems (Wojciechowski, 2004). Teleoperated systems, on the other hand, are known to have increased workload as compared to on-board driving (Draper and Blair, 1996; Dixon et al., 2003; Schipani, 2003). Solutions to this workload have been sought in both (1) the improvement of control and display qualities in the operator station and (2) through the reduction of operator tasks through automation.

The U.S. Army is continually attempting to field systems that further remove soldiers from harm on the battlefield. For the job of mine detection and route-clearing, many systems have been used, but not many have attempted to reduce the workload of the soldier through technology.

1.1 Advanced Robotic Control Modes

The U.S. Army Research Laboratory (ARL) has continually attempted to find ways to improve the Soldier’s performance and survivability by leveraging technology. In this case, General Dynamics Robotic Systems (GDRS) adapted an ARL and U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC) control concept coined “operator biasing” or “biasing” (McDowell, 2008). This concept was originally briefed to TARDEC and had gained popularity in vehicle control systems, as this method is being employed in the Robotic Mine Detection System (RMDS). The RMDS as built by GDRS and Niitek incorporated this concept into their system (a teleoperated leader vehicle, Husky; and a control station follower vehicle, RG-31) in hopes of reducing Soldier workload (figure 1). Other methods of reducing workload were incorporated by introducing cruise control to continually and automatically maintain a desired vehicle speed to reduce workload as well.

The ability to control teleoperated systems will depend mainly upon human factors engineering (HFE) interface design characteristics and without suitably designed controls and displays, there will be an additional workload cost in such systems.

Anecdotal data from a mine clearing system using cruise control suggests that high workload was attributed to the use of cruise control in that system (Haas et al., 1997). Participants used a joystick controller which may have confused the operators. Haas also noted that HFE concerns for this type of slow-moving, sensor-driven system will rely on operator vigilance to counteract the high potential for tedium in such a task.

Figure 1. Husky mine detection and RG-31 control station vehicles.

1.2 Precision Navigation Modes

Precision navigation modes are those that use previously collected global positioning system (GPS) route data for the RMDS system to follow. These are considered semi-autonomous modes and it is predicted that these modes will create less workload and fatigue than teleoperation modes.

Operator biasing is a precision navigation mode that allows the operator to supervise the progress of the teleoperated vehicle, occasionally "bumping" the vehicles path to the right or left in small increments to adjust for poor GPS path data. This method provides a dead man algorithm that requires input from the operator every 30 s, or it will stop the teleoperated system. Operator biasing will be referred to as "Biasing" further in this report.

1.3 Teleoperated Systems Performance Literature

Performance of teleoperated systems has been found to be half that of on-board driving (Scribner and Gombash, 1998). Specifically, performance time to complete a test course for teleoperated driving is about twice that of on-board driving (Mitchell et al., 1994; Scribner and Gombash, 1998). The number of errors (obstacles hit) has been shown to be about double that of on-board or manned driving (Scribner and Gombash, 1998).

The field-of-view (FOV), depth perception (monocular vs. stereovision), camera resolution, and camera distortion can all have an effect on operator workload. It has been found that wide FOV is helpful to operators in unfamiliar terrain (Scribner and Gombash, 1998; Voshell et al., 2005; McGovern, 1987; Silverman, 1982; Kress and Almaula, 1988). Smyth et al. (to be published) concluded that a unity vision display with an electronically controlled FOV might be optimal. To the contrary, Gordon (1966) found that a narrow FOV is adequate if the path is familiar and has no obstacles. Gordon found that operators could drive up to 25 kph on a curved two-lane road with a monocular field as small as 4 degrees. It was concluded that information derived

from the road edges and centerline were sufficient for vehicle steering control. These cues are not available in off-road conditions.

The U.S. Army may conduct a large percentage of missions in off-road and unfamiliar terrain where wide FOV may prove to be a necessity for situational awareness, navigation, and close quarters maneuvering (Glumm et al., 1992).

Wide FOV has shown to aid the teleoperator in accomplishing tasks faster with fewer errors (obstacles contacted) (Scribner and Gombash, 1998; Drascic, 1991), at the cost of increased motion sickness and perceived stress (Scribner and Gombash, 1998; Kress and Almaula, 1988).

1.4 Motion Sickness in Telerobotic Systems

Motion sickness (MS) is defined as the physiological response of the body when the visually perceived movement and vestibular system sense of movement receive disparate cues of motion. MS is often the term used for various types of illness and has been attributed to the body’s innate response to neurotoxin poisoning (Triesman, 1977). When the vestibular and visual systems do not have similar input, the area postrema of the brain is triggered to begin inducement of vomiting. This mismatch of system cues can cause simulator sickness, created by visual movement cues with a lack of movement cues, motion or seasickness, caused by the perceived vestibular motion without visual input.

MS in teleoperated systems has long been a problem due to both the lack of visual fidelity that is associated with the visual systems, and the disparate motion cues from either a stationary or moving command platform.

Tasks on moving platforms are difficult, and can elicit motion sickness effects (Cowings et al., 1999; Hill and Tauson, 2005). The Future Combat System Lead System Integrator performed a demonstration in which the operator teleoperated robotic vehicles from a moving command vehicle (Kamsickas, 2003).   The results showed that motion made all tasks harder, compared to an exercise in a simulated environment, and some tasks (e.g., editing plans and maps, and target acquisition) became almost impossible to perform due to the difficulty experienced by the operators in stabilizing their hand movements. The operators also tended to over steer their robotic vehicles when their own vehicle was turning one way but the robot needed to turn the other way. Motion also makes cognitive tasks more challenging (Schipani, 2003). Schipani evaluated Soldiers’ cognitive performance while in a moving vehicle, and found significant accuracy and speed decrements in performance. Degradations were found in areas such as time sharing, selective attention, inductive reasoning, memorization, and spatial orientation.

The measurement of motion sickness and simulator sickness can be accomplished with one set of measures, as the physiological outcome is the same but can vary widely among individuals. Several measures have been used in recent literature concerning motion sickness, but one in particular has been useful in recent efforts. For this study, the MS inventory by Gianaros et al.

(2001) was selected for use because of its ability to classify MS further into specific areas of effect; gastrointestinal, central nervous system, peripheral nervous system, and sophite-related.

1.5 Workload in Telerobotic Systems

Performance and workload have been assessed for many different types of systems. It has been proposed that the semi-autonomous modes of RMDS control will yield the least amount of operator workload. It has also been proposed that using cruise control will lower operator workload as well. These are all logical assumptions that remain to be tested.

Schipani et al. (1998) found that workload increased as mission distance increased, from 500, 1000, and 2000 m. He also found that workload increased as a function of required operator intervention in a semi-autonomous system. The converse of this, of course, is that workload would be lower for higher levels of autonomy.

Glumm et al. (1996) found that when using a computer-aided teleoperation (CAT) method for extending a teleoperated vehicle's path, that workload was actually higher than that of direct teleoperation. This may have been due to the distance between waypoints which was set at 1 m. This rate of waypoints for the speed of teleoperation may have been considered high workload. Speed averages were 7.6 and 4.7 kph for normal and CAT modes, respectively.

2. Hypotheses

We expected that manned driving, teleoperation, teleoperation with cruise control, and biasing would yield statistically significant performance differences. Specifically, we expected that performance would be significantly better for manned mode than for three remote modes (teleoperation with or without cruise control and biasing modes). We further expected that among remote modes, biasing would yield performance differences that were significantly superior to both teleoperation modes. These four modes are operationally defined in section 3.3.

We expected that subjective workload ratings would be substantially higher for teleoperated remote modes as compared to manned driving mode. We also expected that workload ratings for teleoperation modes would be significantly higher as compared to biasing mode. We were unsure about differences between manned and biasing modes.

We expected that subjective motion sickness ratings would be substantially higher for all remote modes as compared to manned driving mode. We also expected that motion sickness ratings for teleoperation modes would be significantly higher as compared to biasing mode. We also expected a decline in motion sickness ratings over time (four measurements over 1 hr).

This study proposed to examine the performance effects of four types of RMDS control scenarios; manned, teleoperation, teleoperation with cruise control, and biasing modes.

3. Methods

The primary task in this study was a road-edge following vehicle operation task. Participants were instructed to operated the RMDS surrogate vehicle as close to the road edge as possible while attempting to maintain a vehicle speed of 12 kph.

3.1 Participants

Participants were seven U.S. Army Soldiers and one Department of the Army civilian employee, recruited from Fort Belvoir, VA. All participants met requirements for 20/30 visual acuity. Ranks ranged from E-5 to O-5. Age ranged form 22 to 47 years. Three out of eight had robotic systems experience and six out of eight had remote control hobby system experience.

3.2 Apparatus

3.2.1 Volunteer Agreement Affidavit

A Volunteer Agreement Affidavit (VAA) (appendix A) was given to each test participant to review prior to participating in the study. This form was used as the single VAA for several studies performed simultaneously which were all aligned under one research protocol number ARL-20078-08011, entitled "A Comparison of Soldier Performance in a Moving Command Vehicle Under Manned, Teleoperated and Semi-Autonomous Robotic Mine Detector System Control Modes." The VAA used describes this study and others. Upon reading the document, test participants were able to ask all questions concerning their participation in the study. Once they agreed to participate, they signed the document.

3.2.2 Demographic Questionnaire

A demographic questionnaire (appendix B) was administered to collect age, gender, MOS, years in that MOS, and other background information.

3.2.3 Titmus II Vision Testing Device

Participants were screened for 20/30 both-eye visual acuity, far distance using a Titmus II visual-testing device.

3.2.4 ARL Robotics Program Office Fort Indiantown Gap Operations Center

The test course is an 850-m-long course that is similar in nature to a secondary road. This is located at the ARL Robotics Program Office facility at Fort Indiantown Gap, PA. This area has been used in previous tests of teleoperated and autonomous vehicles and operator performance. An orange line was painted along the side of the road for vehicle tracking purposes. This track was driven equally in left and right laps for a total of 6 laps (5100 m). Three laps were driven to

the right and three to the left, alternating the first direction for each test participant. An aerial photograph shows the test course with highlighting in figure 2.

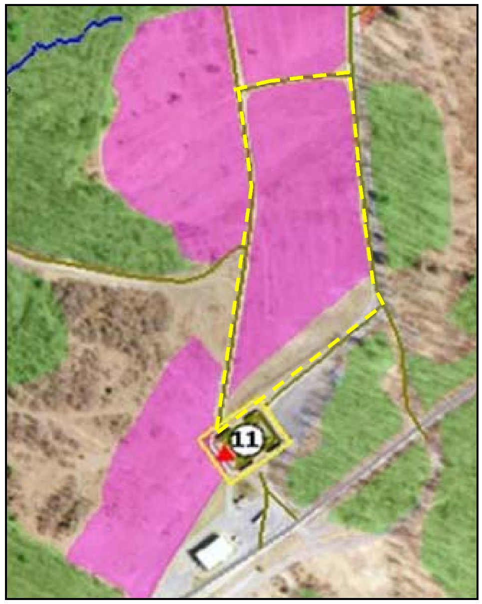

Figure 2. Aerial view of ARL robotics test course (yellow dashed line) at Fort Indiantown Gap, PA.

3.2.5 XUV Teleoperated Vehicle

The Experimental Unmanned Vehicle (XUV) is a four-wheeled teleoperated vehicle outfitted with visual camera sensors (see figure 3).

Figure 3. XUV followed by moving command HMMWV.

3.2.6 RMDS Control Station

The RMDS control station is a variant of the Route Runner control station currently under test for teleoperated HMMWVs. The control station was placed in the command and control shelter of a HMMWV for operations on the move. The video set-up for this study was to use center camera view as the primary display, and a vehicle side camera in the picture-in-picture view for the road edge following task (figure 4). The side camera used was chosen for the corresponding direction that the XUV was travelling (right side for clockwise and left side for counter-clockwise vehicle operation). In all experimental trials, the XUV was followed by the Command Vehicle HMMWV. The control station had a 19-in LCD as its primary visual display.

Figure 4. RMDS surrogate operator control station.

3.2.7 Specific Rating of Events (SRE)

The SRE rating scale (appendix C) (Fatkin et al., 1990) was used for assessing participant global psychological stress. This consists of a numerical scale from 0 to 100 to assess a person's stress at a specified point in time.

3.2.8 NASA Task Load Index (NASA-TLX)

The NASA-TLX (appendix D) (Hart and Straveland, 1988) was used to quantify participant workload ratings under various conditions. The NASA-TLX has been validated with mathematical processing tasks of various levels for workload assessment.

3.2.9 Motion Sickness Assessment Questionnaire (MSAQ)

The MSAQ (appendix E) (Gianaros et al., 2001) will be used to quantify participant workload ratings under various conditions.

3.3 RMDS Control Modes

The RMDS will employ a remotely controlled Husky vehicle commanded from an RG31 command vehicle using an Operator Control Unit mounted in the left rear passenger seat.

The operational RMDS will have various camera configurations available including a center-of-vehicle mounted camera (on top of the cab), forward looking side cameras (mounted on the sides of the vehicle, low to see road edges), and a rear-facing camera for reverse gear. The center and rear cameras have a variable Field of View (FOV) adjustment from 22° to 180°. The RMDS will have the capability to be remotely operated in one of three modes: teleoperation, teleoperation with cruise control, and precision-guided mode. The surrogate system will also provide on-board or manned driving as a baseline comparison to these remote modes.

These modes are described as follows:

- Manned driving: consisted of driving the HMMWV control station vehicle around the course in the same manner as the remote modes.
- Teleoperation: the remote operation of a vehicle using a video camera and primary video display in conjunction with a steering wheel and hand controls for acceleration and braking. There is currently no audio feedback system.
- Teleoperation with cruise control: the previously described mode with the addition of continuous speed control via cruise control, essentially locking the desired speed and easily disengaged with a cancellation of the cruise or with a brake input.
- Biasing: the XUV semi-autonomously follows a previously recorded GPS path with the operator providing: (a) course corrections (bumps) to correct for GPS path error (these bumps are in feet per input via button on the steering wheel) and (b) obstacle detection and avoidance.

3.4 RMDS Vehicle Operation Scenario

The participants reported to GDRS and were provided an overview of the study, at which time initial questions could be asked about the purpose of the study and what was expected. Participants were asked to read and sign the informed consent form if they agreed to participate.

The demographics questionnaire and eye exam were then administered. Participants were then asked to complete the sub-scale comparison phase of the NASA-TLX in which they compared each sub-scale to all other sub-scales on the TLX in order to develop individual scoring weights. Prior to any training, participants received a safety briefing on the operation of teleoperated vehicles and ranges. Participants were informed that they could withdraw from the study at any time for any reason, especially if they felt that they had become motion sick.

Following this training, all four experimental conditions were presented to the participants. There was an optional rest period between trials, yet none of the participants chose to rest in between trials. NASA-TLX, MSAQ, and SRE were all administered after three-lap intervals throughout the duration of each experimental trial.

3.5 Design and Analysis

The design of this experiment was a single factor repeated measures design. The treatment variable had four levels based on type of control mode.

3.5.1 Independent Variables

The variable manipulated in this study was the control mode of vehicle operation in the RMDS. The levels of control mode were:

- Manned driving (baseline performance)
- Teleoperation
- Teleoperation with cruise control
- Biasing

3.5.2 Dependant Variables

The data collected consisted of both objective performance of lateral drift (m), course time (s), and subjective ratings of workload, stress, motion sickness, preference of operational mode, and estimated number of hours of operation in each mode.

4. Procedure and Methodology

As part of the pre-test procedure, participants were given a volunteer agreement affidavit the preceding Monday, which described the study and possible risks. They were then given a short briefing describing the RMDS system and it's control modes. They were then screened for visual acuity using a Titmus II vision-testing device. Demographic data and individual NASA-TLX sub-scale weightings were also collected at this time. All participants were familiarized with the stress (SRE) and motion sickness (MSAQ) rating questionnaires as well.

All participants were given an opportunity to operate the RMDS surrogate system in all three remote modes for a minimum of 20 min. The participants reported in pairs to the ARL DEMO III test facility at Fort Indiantown Gap, PA, to begin study participation.

Participant Scenario

System familiarization was given to each participant prior to the study to ensure that proper and safe operation of the system would be performed. Participants were assigned to their subject ID numbers and subsequent condition orders prior to the experimental data collection day. The order of presentation conditions is presented in table 1. The manned condition is lined-out for participants 4–8 as they did not receive this treatment due to time constraints.

Table 1. Study condition presentation.

Subject	First Scenario	Second Scenario	Third Scenario	Fourth Scenario
1	Teleop	Teleop-cruise	Manned	Biasing
2	Teleop-cruise	Biasing	Teleop	Manned
3	Manned	Teleop	Biasing	Teleop-cruise
4	Biasing	~~Manned~~	Teleop-cruise	Teleop
5	Teleop	Teleop-cruise	~~Manned~~	Biasing
6	Teleop-cruise	Biasing	Teleop	~~Manned~~
7	~~Manned~~	Teleop	Biasing	Teleop-cruise
8	Biasing	~~Manned~~	Teleop-cruise	Teleop

At the experimental test site, participants were given additional training and familiarization with the remote control modes by operating up to two laps around the test course. For each test condition, the participants drove for three laps as accurately as they could while attempting to maintain the maximum speed of 12 kph using their visual display to track the vehicle with the road edge marking. All steering, braking and accelerator controls were performed with the hands using the steering wheel or controls located on the steering wheel. After three laps, the participants were asked to rate their workload by assessing the level of each NASA-TLX subscale, their stress by using the SRE scale, and their motion sickness with the MSAQ. The XUV and control vehicle was turned around and the opposite direction was driven for another three laps with the same battery of questionnaires following completion of the vehicle operation task. At the end of each condition the subject was asked to estimate how many hours they could endure in that condition, to the half-hour. The subject was also asked to rank order the presentation of all conditions in order of personal preference. Test participants were then fully de-briefed and given a point of contact for follow-up on individual performance or results of the study.

All participants in this study were exposed to all control modes, except for participants 4–8 who were only exposed to the remote control conditions. Time to complete the study was hindered by poor weather conditions hence the dropping of the baseline condition (manned) after three participants completed their experimental runs. Groups of two soldiers were brought to the test site to allow for data collection on one day. Each 6-hr period included the following activities:

An assortment of workload, stress, and motion sickness test batteries were administered to each test participant after both three and six laps of each condition. Under each condition, test participants were asked to operate the RMDS surrogate system to follow the identified road edge as accurately as possible while attempting to maintain a maximum speed of 12 kph. The accuracy of the road edge following task was emphasized wile speed maintenance was a secondary priority, but nearly equally as important. Test participants randomly began the test course in a counter-clockwise or clockwise direction and drove three laps to a stop at the course end marker cone. The XUV and the control vehicle were turned around while mid-point questionnaires were administered. Following this, the opposite direction was introduced for another three laps. The test participant was seated at a vehicle control station in the shelter of the control station HMMWV. The control station consisted of a visual display with vehicle control touch panel buttons, and a steering wheel with brake and accelerator paddles for hand control of these functions. The steering wheel also contained buttons for camera control that operated camera zoom, individual camera selection, and picture-in-picture selection. The four test conditions together took ~90 min to complete, varying with weather and system conditions.

Following the study, test participants' motion sickness was assessed to determine if they should remain at the facility due to these effects. None of the eight test participants exhibited even mild effects of motion sickness following the study.

Snacks and beverages were also made available throughout the duration of the testing. Lunch was made available at appropriate times.

5. Results

One-way Analysis of Variances (ANOVAs) were used to examine the effects of various control modes for all dependent measures (alpha = 0.05 significance level). Tukey's Least Significant Difference (LSD) was used as a post-hoc analysis. A summary of all ANOVAs is presented in table 2. The estimated maximum time of operation (hours) is presented in table 3. The rank order operator preference of conditions is presented in table 4.

There were significant findings for the effect of control mode type on many of the dependant variables. Lateral drift ($p = 0.000$), course completion time ($p = 0.000$), and stress ($p = 0.029$) were all found to be significant. There were no significant differences for motion sickness rating data, motion sickness change scores, or stress change scores over time ($p = 0.597$), ($p = 0.541$), and ($p = 0.336$), respectively. The findings for overall workload ($p = 0.058$) and workload change over time ($p = 0.062$) were both non-significant. These two measures will be reported and discussed as they demonstrate important trends in the observed workload data.

Table 2. ANOVA table of dependant measures.

Condition	SS	df	MS	F	P
Lateral Drift (m)					
Lateral drift	3229.24	3	1076.41	61.94	0.000
Error	278.24	16.03	17.37		
Course Completion Time (s)					
Completion time	1578355.15	3	526118.38	7.00	0.003
Error	1201802.33	16	75112.64		
Overall Workload (NASA-TLX)					
Overall workload	789.05	3	263.01	3.05	0.058[a]
Error	1379.55	16	86.22		
Overall Workload Change (NASA-TLX)					
Overall workload	1357.83	3	452.61	2.99	0.062[a]
Error	2414.67	16	150.91		
Motion Sickness (MSAQ)					
Motion sickness	55.00	3	18.36	0.645	0.597
Error	454.61	16	28.41		
Motion Sickness Change (MSAQ)					
Motion sickness change	47.14	3	15.71	0.745	0.541
Error	337.60	16	21.10		
Stress (SRE)					
Overall workload	764.19	3	254.73	0 4.12	0.029
Error	803.46	13	61.80		
Stress Change (SRE)					
Motion sickness change	204.36	3	68.12	1.239	0.336
Error	714.96	16	54.98		

[a]Indicates nearly significant data that will be presented and discussed further.

Table 3. Estimated maximum operation time by mode type (n = 8).

Operation Mode	Mean Estimated Operation Time (hr)	S. D.
Manned	6.66	2.30
Teleoperated	3.68	2.29
Teleoperated with cruise control	4.31	2.65
Biasing	5.18	3.20

Table 4. Rank order of preferred remote operation modes (n = 8).

Operation Mode	First Choice	Second Choice	Third Choice
Teleop	2	0	6
Teleop with CC	0	7	1
Biasing	6	1	1

The data for workload, motion sickness, and stress were calculated by averaging the mid and final workload scores to assess an overall average for each condition. The workload, motion sickness and stress change scores were calculated by subtracting the final scores from the mid-point scores. The data for the significant (and two nearly significant) results are depicted in figures 5–9. Boxes in the data graphics indicate that significant differences were found among cells for the post-hoc test.

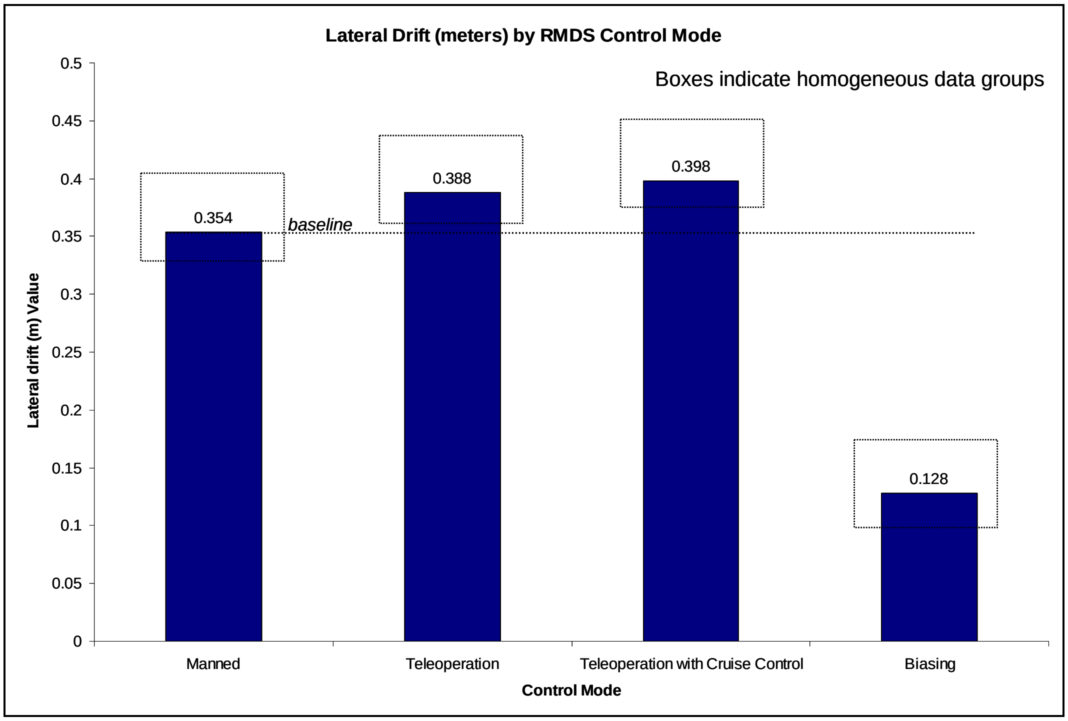

Figure 5. Lateral drift (m) by control mode (p = 0.000).

The least amount of lateral drift was exhibited by the biasing condition, followed by manned, teleoperated, and teleoperated with cruise control (figure 5).

Course completion times showed that manned driving was significantly faster than all the remote modes as a single group (figure 6).

Overall workload ratings yielded significant post-hoc analyses that were all significantly different from each other, with the lowest rating for the biasing condition. Manned operation showed a lower rating than the two teleoperated modes, while the pure teleoperation mode yielded the highest workload ratings (figure 7).

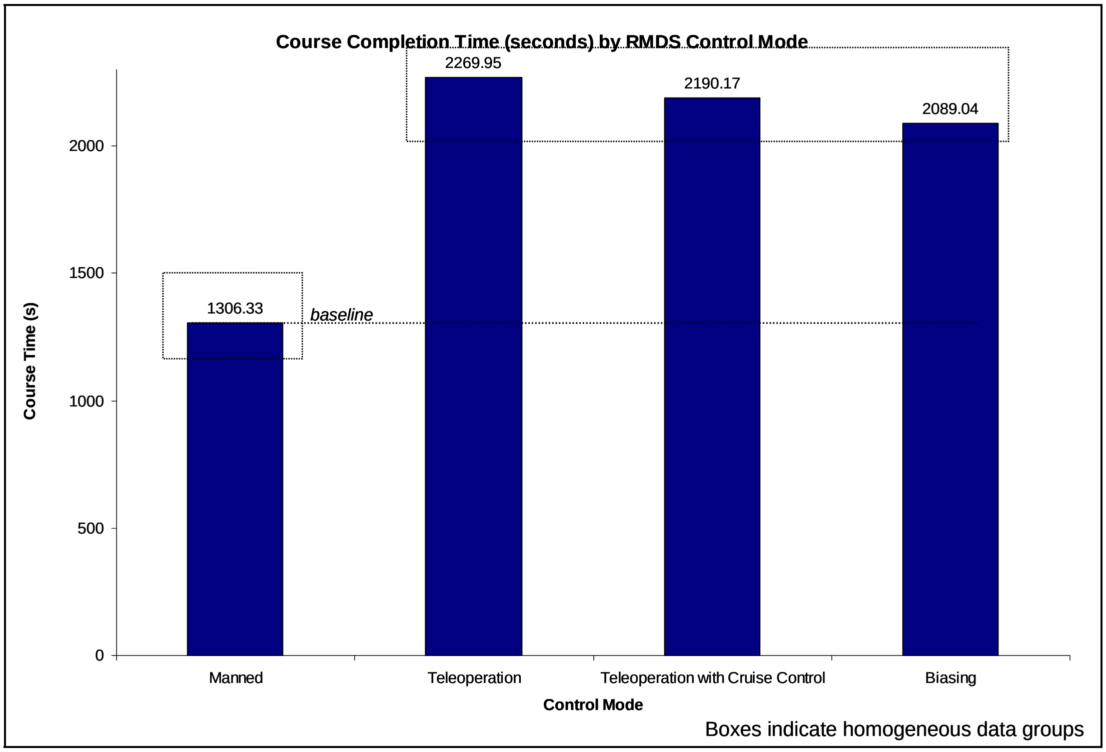

Figure 6. Course time (s) by control mode (p = 0.000).

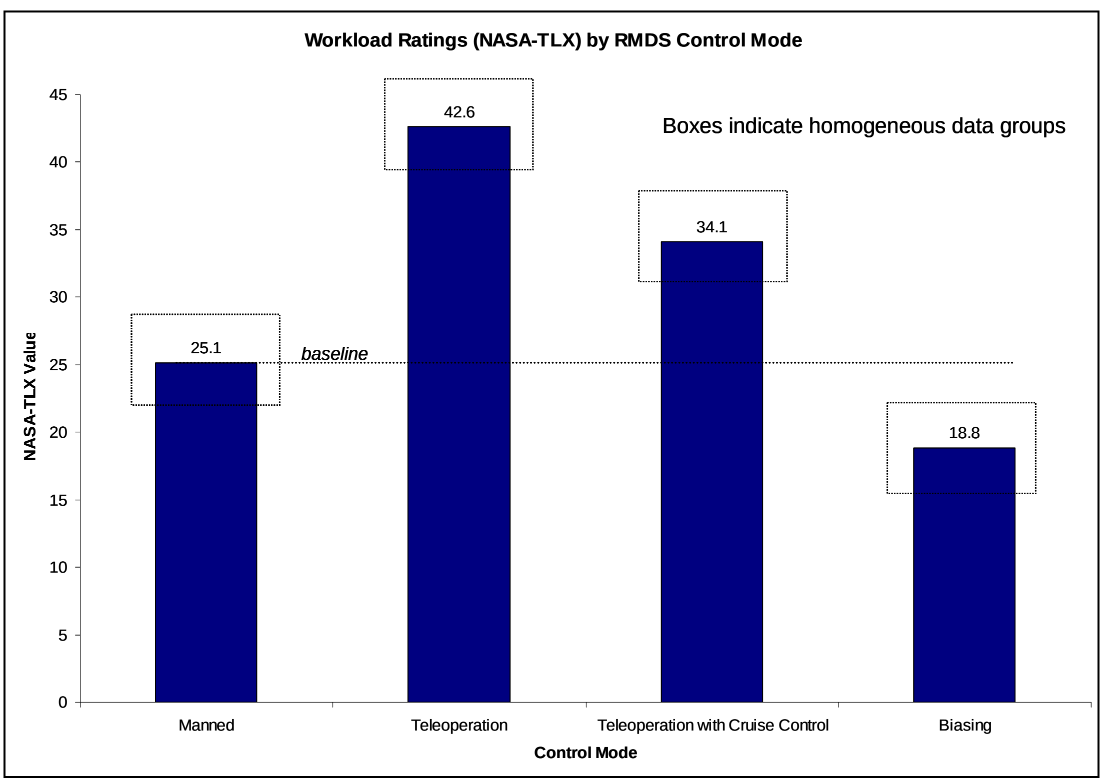

Figure 7. Overall workload ratings by control mode (p = 0.058.)

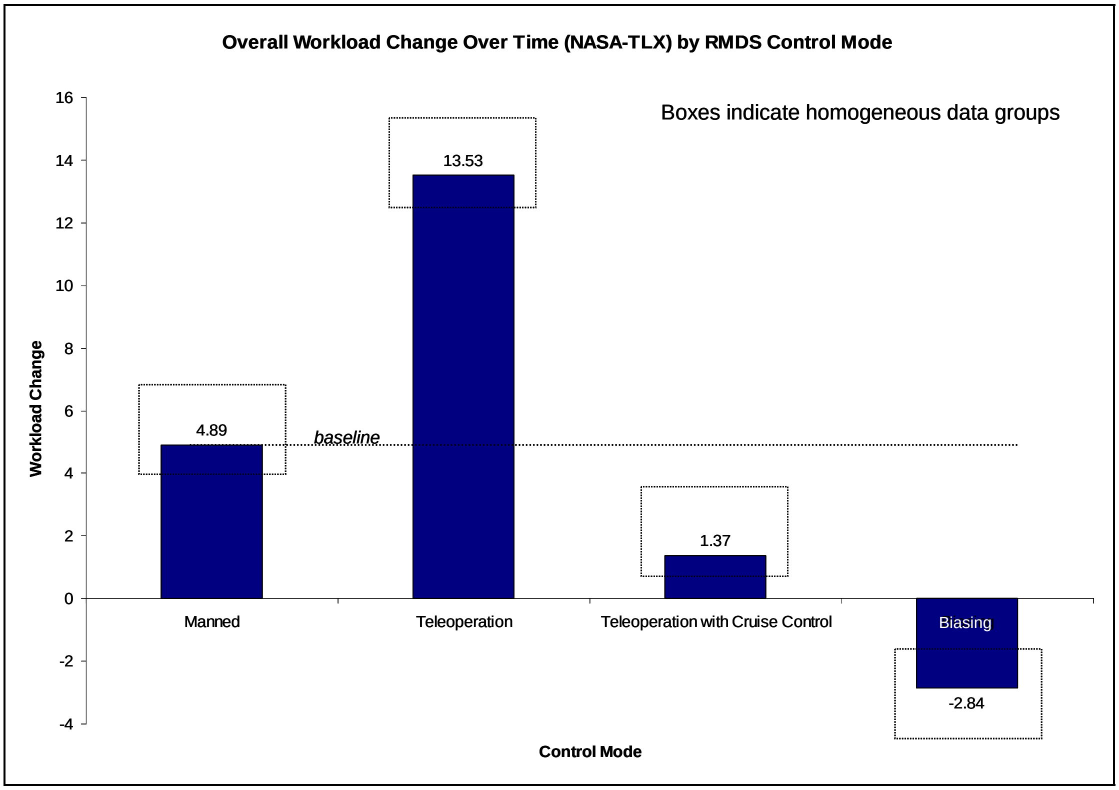

Figure 8. Overall workload change scores by control mode (p = 0.062).

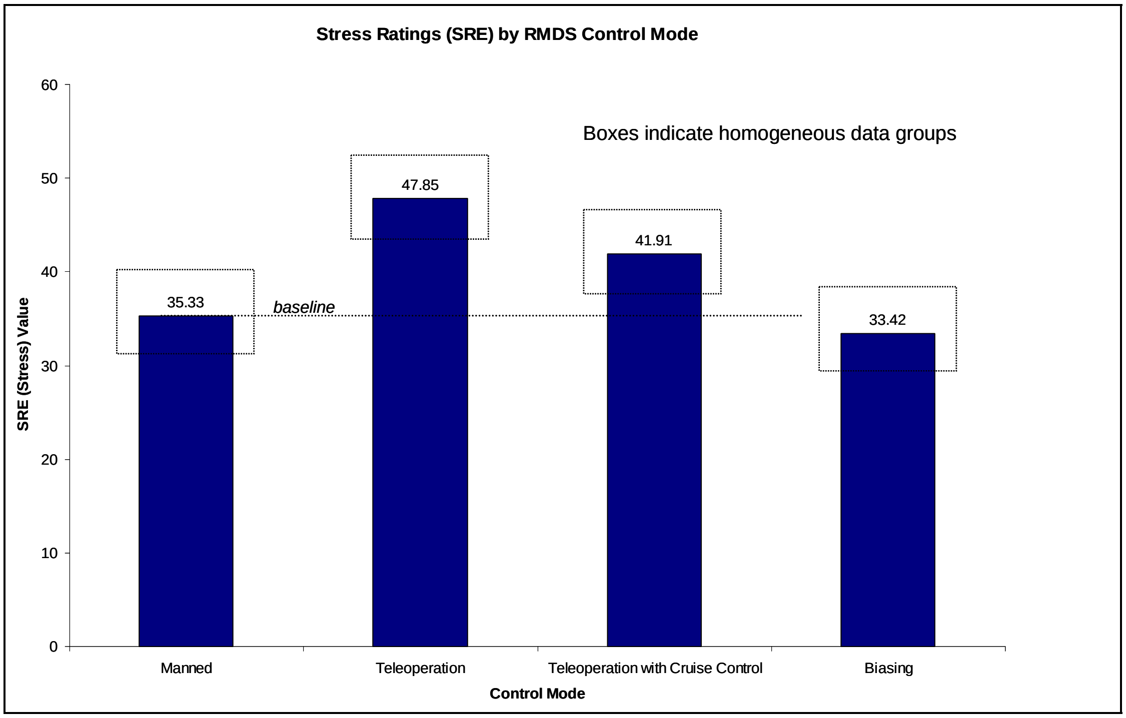

Figure 9. Stress ratings by control mode (p = 0.029).

Overall workload change post-hoc scores revealed that different modes will have different change effects over time. The notable finding in this data was the very high positive change in workload for the pure teleoperation mode. The other interesting finding is the isolated small negative change in workload for the biasing condition. This was the only negative change in the data (figure 8).

Stress ratings were all significantly different from each other, with the lowest rating for the biasing condition. Manned operation showed a lower rating than the two teleoperated modes, while the pure teleoperation mode yielded the highest workload ratings. The stress data patterned identically with the workload condition, showing a high correlation between stress and workload (figure 9). The Pearson correlation coefficient was significant ($p = 0.01$) and calculated to be $r = 0 .907$, $df = 23,27$ for stress and workload, respectively.

6. Discussion

The first hypothesis of performance differences for control mode was supported by the significant differences among the four operation modes as evidenced by the dependant measure outcomes. The measure of lateral drift showed a remarkable level of significance ($p < 0.000$) for this measure. Manned mode was significantly better than both teleoperation modes, and pure teleoperation mode was superior in performance to teleoperation with cruise control, but only by about 0.01 ms, or 1 cm. Thus, the practical difference between the two teleoperated modes was negligible. The surprising outcome was that biasing mode was not only superior to both teleoperation modes, it surpassed manned mode by a large margin. In retrospect, this may not be so surprising, as the GPS following capability worked remarkably well for semi-autonomous vehicle control.

The course completion time data showed that manned driving is still superior to all of the remote condition times. In, fact all of the remote modes were within about 40 s of each other, while the manned mode was better by a margin of 876 s, or about 14.6 min. In terms of minutes, the manned mode required about 21.7 min per trial, while the remote modes required about 36.4 min per trial. Course time data very closely support the data of Scribner and Gombash (1998) and Mitchell et al., (1994) who found that teleoperated time requirements were about double that of manned operation. It is interesting to note that the speedometer of the HMMWV was not well-suited to display an accurate speed, as drivers averaged much faster speeds while manned driving.

The second hypothesis of superior performance for the manned mode was also supported by the data, as the workload for manned mode was far lower than the two teleoperated modes. This data supports the previous work of Draper and Blair (1996), Dixon et al. (2003), and Schipani (2003). In particular, Schipani (2003) stated that workload increased as a function of distance.

This finding is supported by the data for modes except for biasing which contradicts Schipani's findings. In fact, the biasing mode had the opposite effect with a decreasing workload from about 2500 to 5000 m in distance traveled. However, Schipani (2003) is supported in the notion that workload is increased for higher levels of operator involvement. The data herein do not support the findings of Glumm et al. (1996) who found that computer aided teleoperation had higher workload than direct teleoperation. It was found that the workload of teleoperated driving was significantly higher than teleoperation with cruise control, showing the obvious benefit of removing that task from the operator's workload. A surprising result was found for workload in the biasing mode, in that it was significantly lower than manned driving. Another interesting result was the negative change score in overall workload for the biasing condition. Stress scores mirrored the overall workload data and could be supported by similar data reported by Scribner and Harper (2001).

The third hypothesis of operator motion sickness for remote modes was not supported, due to non-significant differences for the motion sickness ratings and motion sickness change scores over time.

It appears that most of the significant differences were yielded for the measures of lateral drift and course time. Biasing mode clearly held the widest advantage for its ability to allow minimal lateral oscillation of the XUV. The differences between manned and teleoperated modes were significant, yet it must be noted that the differences were within a range of about 4.5 cm. As for course completion times, manned operation was certainly the clear winner, as course times were several minutes longer for the remote modes. Motion sickness had no discernable effect to be measured among conditions, however, workload ratings and workload change scores over time hold some very interesting points to discuss. Workload is clearly lowest in the biasing condition, followed by manned operation, teleoperated with cruise control, and teleoperation. The workload for teleoperation was the highest, clearly as a result of the tasks required with the RMDS control station. The effect of removing the speed control task by adding cruise control technology significantly reduced operator workload, while removing the tasks of speed and steering control altogether, requiring only occasional operator "biasing" inputs, reduced the workload over teleoperation by 50%. The biasing workload was the lowest workload condition of all.

Operator preference data clearly showed that the biasing mode was preferred from among all remote control modes. The rank ordering shows that teleoperation with cruise control and teleoperation were second and third choices for the participants, respectively. The estimated number of operational control hours was highest for the manned condition followed by biasing, teleoperation with cruise control, and teleoperation. This shows that the operators felt that they could operate under manned conditions the longest period of time, followed by biasing, event though biasing was rated lower in workload than the manned condition. This is a curious result

that may be attributable to operator's opinions of tasks requiring vigilance (biasing) vs. workload (manned) required in these modes. The higher arousal requirement of manned driving may be more preferable than the lower arousal requirement of biasing.

7. Conclusions

The data seem to indicate that the best condition to allow lengthy operator involvement with simultaneous secondary tasks would be the biasing condition. This has caveats associated with it. First, the route to be cleared would require that a "library" of GPS data exist that contains the route to be followed, otherwise, manned or teleoperation conditions would be required. Second, the workload decline of the biasing condition may lead to operator boredom requiring specific alerting and forced input to reduce the occurrences of inattention and low arousal, which the RMDS system does currently employ.

The data also indicate that if a Soldier is best removed from danger via remote modes, then route-clearing missions be performed in teleoperation with cruise control mode, as the tradeoff appears best for this mode considering lateral drift, course time, and workload differences. If GPS data is required for a new route, and danger is low, it appears that manned driving would be the best condition based on lateral drift, workload, and stress data. Superior speeds cannot be used as criteria for mission selection in this case because the desired speed was exceeded by manned operation in the manned trials which would have rendered the sensors ineffective. In other words, if reducing workload while route clearing in low danger areas is a priority, it would seem that manned driving would be the best option.

Motion sickness data in this study were non-significant due to the obvious low-speed application of the surrogate system. With other teleoperated systems, motion sickness appears to make significant effects in speed bands beyond 10 mph. As this system works at an optimal speed of 12 kph (7.5 mph) this effect is understandably not apparent except in very mild and rapidly dissipating form for most operators. The control shelter did contain one window; however, this window was located high and forward of the control station. Its effect upon motion sickness scores is unknown.

In future research of this type, it would be recommended that various road surface types be used to examine the effect for different control modes. It is known that road surface can have a large effect on teleoperated and even normal driving performance. Additionally, visual display factors such as field of view, resolution, and apparent frame rate could be examined to determine their effects on operator performance in these conditions. Other tasks such as mine detection sensor monitoring or communication tasks were not addressed in this study and could be examined in future research.

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Appendix A. Volunteer Agreement Affidavit

This appendix appears in its original form, without editorial change.

VOLUNTEER AGREEMENT AFFIDAVIT:

ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:	**U.S. Army Research Laboratory Human Research and Engineering Directorate Aberdeen Proving Ground, MD 21005**

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 USC 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities]
Principal purpose:	To document voluntary participation in the Research program.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for participants in approved Department of Army research projects

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of *participating in this project (under the provisions of AR 40-38 and AR 70-25).*

Part B • To be completed by the Principal Investigator

Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.

Title of Research Project:	A Robotic Control Mode Study for a Robotic Mine Detection System	
Human Use Protocol Log # Number:	**ARL-20098-08011**	
Principal Investigator:	David Scribner	Phone: 410-278-5983 E-Mail: dscribne@arl.army.mil
Associate Investigator:	David Dahn	Phone: 410-935-6765 E-Mail: ddahn@alionscience.org
Location of Research:	General Dynamics Robotic Systems, Westminster, MD	
Dates of Participation:	14-31 February 2008	

Purpose of the Research

You are invited to participate in a study designed to evaluate the effects of different control methods for a remote control, or teleoperated mine detection system. More specifically, the purpose of this study is to compare four different methods of control and their effects on route path quality, course time, and ratings of mental effort, motion sickness, and stress. This study will be conducted the Army Research Laboratory (ARL) – Human Research Engineering Directorate (HRED) at General Dynamics Robotic Systems (GDRS) in Westminster, Maryland..

Procedures

Participation in this study will require a one day of visit to the test course facility at GDRS in Westminster and a one-day visit to the test facility at Ft. Indiantown Gap, PA. On the first day, you will be asked to (1) provide written informed consent to participate in the study, (2) choose whether or not to provide the principle investigator your ASVAB scores (3) be assigned a confidential participant ID number, (4) complete a demographics questionnaire, and (5) be tested for visual acuity and color vision. After this, you will be familiarized with the teleoperated system, the test course, and safety procedures pertaining to the operation of the system. You will train on one day at the beginning of the week on how to specifically operate all four modes of control for the teleoperated system. On the second day, you will be exposed to four experimental trials, each for one of the modes of control. Following this, you will be de-briefed and given information on how to contact the researcher for questions that you may have about your data or the study after it is complete.

There is a risk of motion sickness in this study, as you will be moving in a vehicle that follows the teleoperated vehicle, at speeds up to but not exceeding 7.5 mph. This is considered a slow speed, which should not generate incapacitating motion sickness. You are free to withdraw

from this study at any time for any reason, including feeling any effects of motion sickness. You will be operating inside of a vehicle that will be heated and provide shelter from weather effects such as wind and precipitation. You will be asked to wear a seat belt at all times when operating the vehicle. You will also be asked to wear a safety helmet for protection when inside the control vehicle.

You will be asked to complete a set of pre-test questionnaires including a sub-scale comparison for the workload and stress questionnaires. You will be asked to fill out workload, motion sickness, and stress questionnaires after each 5 laps per experimental trial. The test course you will operate the vehicle on is approximately 600 meters in length. You will operate 10 laps in one direction and then 10 in the other direction. One run will be about an hour long. You will be permitted to have a break for 30 minutes between trials. This will require approximately 6 hours in all. You may not be eligible to participate in this study if: (1) your visual acuity is less than 20/30 when corrected with glasses or contact lenses, or if 2) your medical profile indicates that your health status requires approval by your physician.

Benefits

You will receive no benefits from participating in the project, other than the personal satisfaction of supporting research efforts to better understand factors that affect differences in various remote control modes for teleoperated mine detection systems.

Risks

Risks associated with this evaluation are minimal and are less than those encountered by Soldiers during their normal field training exercises or by civilians driving on public roads. There is a minimal risk of motion sickness and steps will be taken to prepare for this possibility. These steps include having a motion sickness bag and pre-soaked sterile wipes and hand sanitizer available in case of vomiting. There will also be refreshments offered and a place to sit comfortably or lie down for any time period required. If you develop motion sickness symptoms, we will ask you to remain at the site until symptoms disappear.

Members of the test administration staff will be close to you throughout all evaluation trials to assist you should a problem arise. If you ask to terminate the test, care will be taken to minimize risks and you will be allowed to cease participation. If the WBGT equals or exceeds 85°F testing will be halted. You will have a break of at least 20 minutes between operations conditions.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. Photographic or video images of you taken during this data collection will not be identified with any of your personal information (name, rank, or status). Your facial features and name will be blurred out of any still photos. Video footage will be taken at such an angle that you will not be able to be positively identified. Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Human Research Protection Office officials may inspect the records.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The Principal Investigator will provide a copy of the signed and initialed Affidavit to you.

Obtaining of ASVAB Scores

IF YOU ARE AN ACTIVE DUTY ENLISTED MILITARY VOLUNTEER, we would like to obtain your Armed Services Vocational Aptitude Battery (ASVAB) scores for potential data analysis. The ASVAB scores would be used strictly for research purposes. The results of any such analyses would be presented for the group of participants as a whole; and no names will be used. With your permission, we will obtain these scores by sending a copy of this signed consent form along with your Social Security Number to the Defense Manpower Data Center (DMDC) in Seaside, CA where ASVAB scores may be obtained from their databases in Arlington, VA or Seaside, CA. If you do not wish your ASVAB scores to be released to the principal investigator, you will still be allowed to participate in the research.

If you would like to participate in this research, please sign one of the following statements, and then complete the information requested at the end of this form:

I **DO AUTHORIZE** you to obtain my ASVAB scores. ______________________________
(Your Signature)

I **DO NOT AUTHORIZE** you to obtain my ASVAB scores.

____
(Your Signature)

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee **U.S. Army Research Laboratory** **Human Research and Engineering Directorate** **Aberdeen Proving Ground, MD 21005** **(410) 278-5992 or (DSN) 298-5992**	**OR**	**Office of the Chief Counsel** **U.S. Army Research Laboratory** **2800 Powder Mill Road** **Adelphi, MD 20783-1197** **(301) 394-1070 or (DSN) 290-1070**

I do hereby volunteer to participate in the research project described in this document. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 410-278-5992 or DSN 298-5992.** I understand that any published data will not

reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.

Printed Name Of Volunteer (First, MI., Last)	
Social Security Number (SSN)	***Permanent Address Of Volunteer***
Date Of Birth (Month, Day, Year)	
Today's Date (Month, Day, Year)	***Signature Of Volunteer***
Signature Of Administrator	

Appendix B. Demographic Data Collection Form

This appendix appears in its original form, without editorial change.

DEMOGRAPHICS AND EXPERIENCE QUESTIONNAIRE Soldier ID ___

Age_____ Height ___ ft ___ in Weight _____lbs

Rank______ Date entered military (month)_______ (year)______

Date Armed Services Vocational Aptitude Battery (ASVAB) taken (month)_____ (Year)_____N/A_____

If applicable, Primary MOS______ Secondary MOS______ OR Job Title____

1. Have you operated a remote military system before? ____Yes ____No

2. Have you operated radio-controlled hobby systems before? (Car, plane) ____Yes ____No

3. How well do you feel you perform with a remote vehicles?

____Poor ____Below Average ____Average ____Above Average ____Excellent

4. Does your Military Occupational Specialty include driving any vehicles? ____Yes ____No

5. Are you ____left handed or ____right handed?

6. Do you use your ____left eye or ____right eye to aim a weapon?

7. Do you wear glasses/contact lenses when you drive ? ___ Yes ___ No

8. a. Do you play video games or computer games? ___Yes ___No

b. What type of specific systems do you use? ___ Console ____ PC ____Both

9. Do you ever play simulations or games that have driving involved? ____Yes ____No

10. How well do you think you play driving video games?
____Poor ____Below Average ____Average ____Above Average ____Excellent

11. What is your current education level?

____High School ____Junior College ____Bachelor's Degree ____MA ____PhD

12. How susceptible are you to motion sickness? ___Low ___Moderate ____ high

---

Vision Testing Score: (Acuity)___________________________ (Color Vision)_________

Appendix C. Specific Rating Of Events (SRE) Form

This appendix appears in its original form, without editorial change.

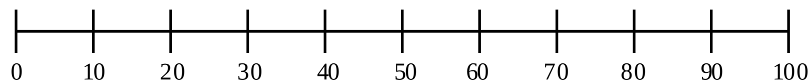
Soldier ID: ______________________
Date:____________________________
Condition:________________________

PRE-EXPERIMENTAL RUN (BASELINE)

1. The scale below represents a range of how stressful an event might be. Put an "X" on the line to rate how much stress you experienced right now?.

Not at All Stressful

Most Stress Possible



2. At what number value does the "X" touch the line? ________

Soldier ID: ______________________
Date:___________________________
Condition:_______________________

PRE-EXPERIMENTAL RUN

1. The scale below represents a range of how stressful an event might be. Put an "X" on the line to rate how much stress are you experiencing currently <u>during this vehicle operation?.</u>

Not at All Stressful — Most Stress Possible

0 10 20 30 40 50 60 70 80 90 100

2. At what number value does the "X" touch the line? ________

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Appendix D. NASA Task Load Index (NASA-TLX)

This appendix appears in its original form, without editorial change.

NASA-TLX Workload Quesitonnaire (Weighting Selection)

Soldier ID_________
Date___/___/___

(one time only, per test participant)

For each pair, select the one element that is more important for measurement of workload for the task.

☐	Mental Demand	/	Physical Demand	☐
☐	Mental demand	/	Temporal Demand	☐
☐	Mental Demand	/	Performance	☐
☐	Mental Demand	/	Effort	☐
☐	Mental Demand	/	Frustration	☐
☐	Physical demand	/	Temporal Demand	☐
☐	Physical Demand	/	Performance	☐
☐	Physical Demand	/	Effort	☐
☐	Physical Demand	/	Frustration	☐
☐	Temporal Demand	/	Performance	☐
☐	Temporal Demand	/	Effort	☐
☐	Temporal Demand	/	Frustration	☐
☐	Performance	/	Effort	☐
☐	Performance	/	Frustration	☐
☐	Effort	/	Frustration	☐

NASA-TLX RATING SCALE DEFINITIONS

MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*L o w/High*	How much physical activity was required (e.g.. pushing, pulling, turning, controlling, activating,, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous restful or laborious?
TEMPORAL DEMAND	*L o* w/Hig*h*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*Poor/Good*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish)'our level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? .

NASA-TLX Workload Questionnaire (Weighting Selection)

Soldier ID_______________
Date___________________
Condition_______________

For each workload element listed below, please indicate (with an exact mark on the line) how much each element contributed to your overall workload experienced in the task you just performed. Please write the corresponding number for your mark in the space provided below each line.

Mental Workload

0 100
Low High

What number is this?_____

Physical demand

0 100
Low High

What number is this?_____

Temporal Demand

0 100
Low High

What number is this?_____

Performance

0 100
Low High

What number is this?_____

Effort

0 100
Low High

What number is this?_____

Frustration

0 100
Low High

What number is this?_____

Appendix E. Motion Sickness Assessment Questionnaire (MSAQ) Form

This appendix appears in its original form, without editorial change.

Motion Sickness Assessment Questionnaire

Soldier ID ________________

Date _____________________

Condition:_________________

Using the scale below, pleasecircle the number that rates how accurately the following statements describe your experience.

	Not at all		Severely
1. I felt sick to my stomach	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
2. I felt faint-like	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
3. I felt annoyed / irritated	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
4. I felt sweaty	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
5. I felt queasy	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
6. I felt lightheaded	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
7. I felt drowsy	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
8. I felt clammy / cold sweat	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
9. I felt disoriented	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
10. I felt tired / fatigued	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
11. I felt nauseated	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
12. I felt hot / warm	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
13. I felt dizzy	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
14. I felt like I was spinning	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
15. I felt as if I may vomit	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely
16. I felt uneasy	Not at all	1-------2-------3-------4-------5-------6-------7-------8-------9	Severely

17. How many times have you vomited today? _________

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